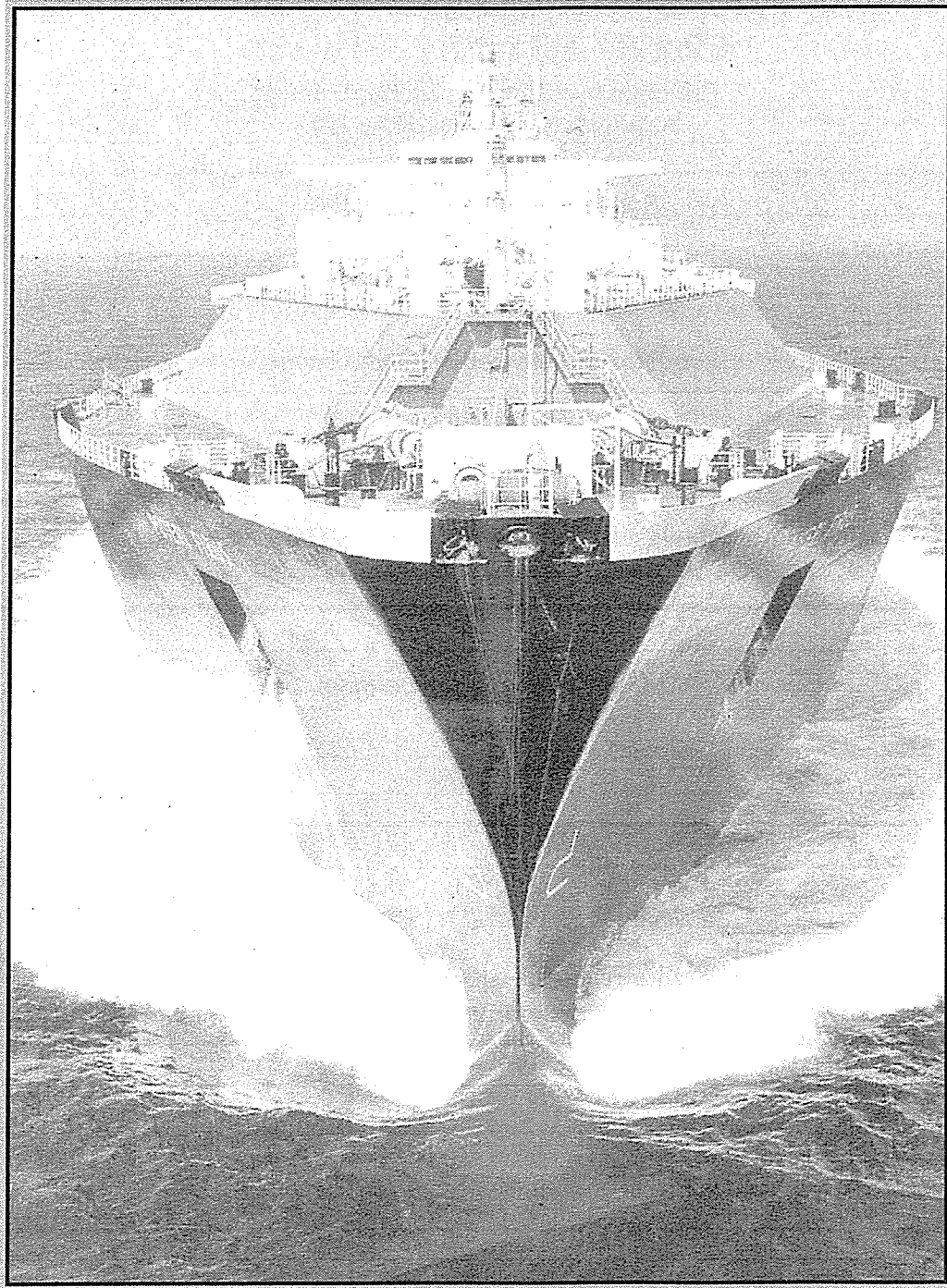
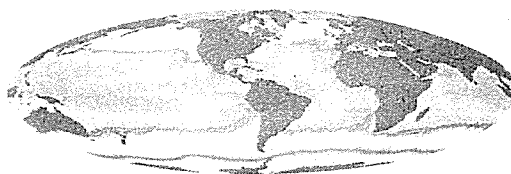


*LNG Supply Chain Greenhouse Gas
Emissions for the Cabrillo Deepwater Port:
Natural Gas from Australia to California*



By Richard Heede
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7 May 2006



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to Pam-e for her red-headed wisdom

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Cover: *Puteri Firus* sailing for Shell International Trading & Shipping, Alstom/Chantiers, shipbuilder, www.marine.alstom.com

LNG Supply Chain Greenhouse Gas Emissions,

In which natural gas from BHP Billiton's Scarborough offshore field is extracted, transported by subsea pipeline to the proposed Pilbara LNG plant near Onslow, Western Australia, where the gas is liquefied, shipped by LNG carrier to Cabrillo Deepwater Port offshore Ventura County, and finally combusted by SoCalGas' end-use customers in southern California.

Introduction

This report summarizes an analysis of greenhouse gas emissions from the entire supply chain as identified by BHP Billiton, the project's applicant, as the likely source of natural gas delivered as LNG to the Cabrillo Deepwater Port receiving terminal offshore Los Angeles, Malibu, and Oxnard, California. BHP has presented and the California State Lands Commission (CSLC) has reviewed what appear to be reliable estimates of most of the greenhouse gas emissions arising from start-up and yearly operation of the Cabrillo facility. No attempt was made by BHP or by the CSLC to include emissions from other critical links in the delivery chain from the production of natural gas in Australia through to its consumption by California gas customers. This interpretation of what constitutes greenhouse gases emissions arising from a proposed energy project is too narrow.

Climate Mitigation Services was commissioned by the Environmental Defense Center on behalf of the California Coastal Protection Network to fill this analytical gap. The Cabrillo Deepwater Port, as this analysis will show, is the source of only 1.5 percent of the full range of emissions from the supply chain summarized in this report.

What follows is an identification of the major segments of the supply chain as described by BHP in its *Construction Permit Application* and by the CSLC in its *Revised Draft Environmental Impact Report*. The report quantifies the pertinent emissions of greenhouse gases from each of these segments.

Study Objectives

This study's objective is to take a comprehensive view of a proposed new source of natural gas to southern California customers — the Cabrillo Deepwater Port — and estimate total emissions of greenhouse gases from the production of the delivered gas to its combustion by end-users. The Liquefied Natural Gas (LNG) receiving and re-gasification terminal is intended to supply 800 million cubic feet of natural gas per day (equal to the energy contained in ~7 million gallons of gasoline per day), according to BHP Billiton, the Australian multi-national energy and minerals company proposing to build the Cabrillo facility 14 miles offshore Ventura County.

BHP has estimated greenhouse gas emissions from the operation of the Cabrillo Deepwater Port as part of its permit application to the U.S. Coast Guard and the State of California. While the BHP application also estimates impacts on air quality, water discharges, land use, ocean bottom disturbances, etc., the purpose of the present analysis is to estimate emissions of greenhouse gases across the entire supply chain of natural gas — from its production platform offshore Western Australia and across the Pacific Ocean to California, including liquefaction and other significant emissions sources. Emissions from the combustion of the delivered natural gas by

California gas customers are also included (after deducting for minor non-fuel uses of natural gas). This allows a meaningful comparison of total supply chain emissions to those from the Cabrillo Port estimated by BHP Billiton in its *Construction Permit Application*.

Each emissions source and the methodology used to quantify them are fully documented in the appended spreadsheets. This report summarizes the major segments of the supply chain, the main sources of greenhouse gases in each segment, and quantifies emissions from each link in the chain that may, if BHP is successful, connect California's gas power plants and water heaters to a natural gas field offshore Western Australia.

This summary report cannot substitute for the details contained in the attached spreadsheets and their cell notes. CMS relies on BHP-supplied data when feasible, and upon industry practice and reasonable (and fully documented) performance indicators when estimating emissions beyond the limited scope of BHP's own estimates. Nonetheless, it is important to state clearly that the results summarized herein are *estimates* and are made without access to detailed engineering analyses only available to BHP, and in many cases are merely in the early planning stages.

It is not our purpose to attribute the entirety of the supply chain emissions to BHP. Rather, the purpose is to fully account for all the emissions attributable to the proposed project from start to finish, from production to combustion. Cabrillo is not isolated from the rest of the supply: it relies on Australian gas that has to be liquefied and shipped at considerable environmental and capital cost, and the gas supplied by the Cabrillo regasification plant will be burned in appliances and turbines in California. State agency officials and the California public cannot make an adequate assessment of the pros and cons of the proposed project without information on the broader scope. This study does *not* evaluate alternative means of delivering energy resources to California, and no recommendations for or against this project will be made.¹

Both "high" and "low" estimates are calculated and fully documented in the attached set of worksheets and tables; we generally report the average of high and low in this summary. Note: CMS reports LNG and emissions in metric tonnes (1 tonne = 1.1023 short tons).

Boundary definition

This study identifies and quantifies all significant sources of greenhouse gas emissions inherently linked to BHP's delivery of natural gas to southern California. The boundary commences both temporally and geographically with the production of natural gas offshore Western Australia. Energy-related combustion and process emissions across the supply chain are within the boundary. The chain ends with the combustion of the delivered gas by California gas customers. The gases included in the inventory are carbon dioxide and methane from combustion sources, process emissions, and fugitive and/or vented sources.

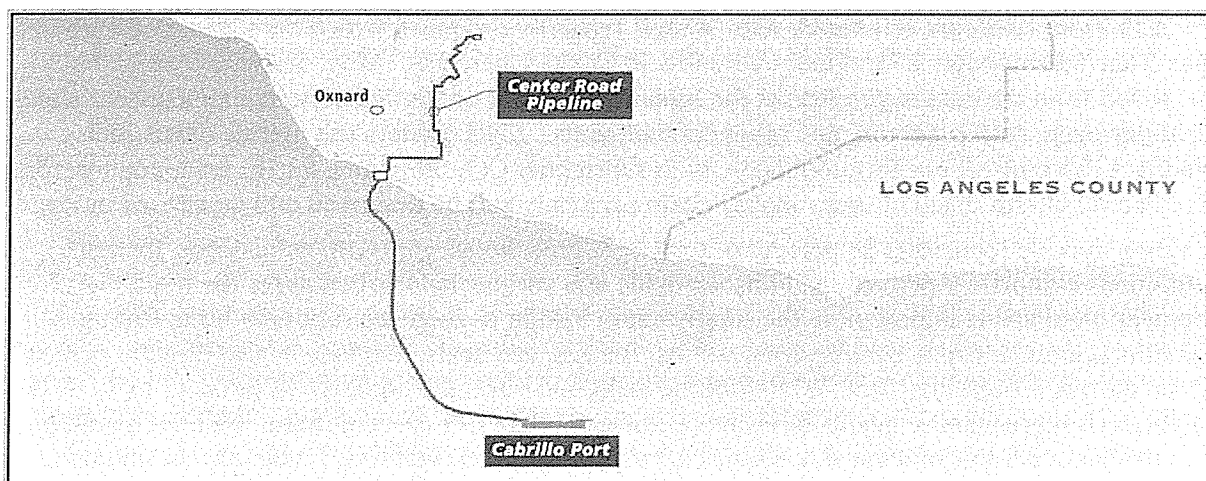
Nitrous oxide and halocarbon emissions sources are *not* included, except for a minor amount of N₂O from the liquefaction plant.² Also excluded are emissions from the materials embodied in

¹ The uses of BHP's delivered gas are numerous, and a detailed assessment would need to be done to adequately compare options such as domestic natural gas, hydrogen, renewable energy, end-use efficiency, or alternate sources of LNG. Interested readers might start with Hunt et al (2006) *Does California Need Liquefied Natural Gas?*

² Potential emissions of halocarbon leakage or off-gassing during the manufacture, installation, and use of insulation materials in cryogenic storage tanks, pipelines, and LNG carriers have not been quantified. The value chain contains on the order of 10⁵ m³ of insulation material. These include rigid foams (polystyrene, polyurethane, and phenolic resins) and bulk zeolites. Liquefaction plants typically use propane and/or mixed refrigerants; van de Graaf (2006).

the supply chain, such as the ~600,000 tonnes of steel built into production platforms, pipelines, liquefaction plant, fleet of LNG carriers, storage tanks, and the offshore Cabrillo facility.³

Energy consumption and emissions from shipyards, engine manufacturers, and the offices of naval architects and plant engineers are similarly outside the boundary, even though these emissions are at least partially attributable to the creation of the supply chain in question. Nor is travel by BHP managers from Perth included, or commuting to work by hundreds of Cabrillo Port construction workers (except for emissions from fuel used by crew boats). The emissions from manufacturing and towing the 200,000-tonne Cabrillo Port to its offshore site, or mooring it to the seafloor, are also excluded. Although omitted by BHP, CMS has estimated emissions from the construction of the pipeline connecting the Cabrillo facility to onshore gas utilities.



Location of the Cabrillo Deepwater Port facility. Source: California State Lands Commission (2006).

Supply chain description

In brief, the delivery of gas to southern California markets via the proposed Cabrillo Floating Storage and Regasification Unit (FSRU) is accomplished by transporting the gas produced from the offshore Scarborough natural gas field by a production platform on (yet to be built) through a 170-mile (280-km) subsea pipeline (yet to be built) to a large gas processing plant being planned near Onslow, Western Australia (population of 800).

This plant (yet to be built) would remove impurities and liquefy nearly 8 million tonnes of natural gas per year by chilling the gas, now mostly methane, to minus 259 °F. At this point it is liquefied natural gas (hereafter LNG), and its volume has decreased by a factor of 600, enabling it to be economically shipped in a fleet of LNG carriers (yet to be built) across the Pacific Ocean to California, where it will be re-gasified by adding heat to the LNG in the Cabrillo FSRU (yet to be built), and piped to shore in a planned pair of 24-inch pipelines. The LNG business is not new; in fact Japan has imported LNG for power generation and heating needs for decades, including from an LNG plant in Kenai, Alaska.

³ CMS does *not* include the roughly estimated 700,000 tonnes of CO₂ from the fabrication of 570,000 tonnes of steel at ~1.24 tonne CO₂ per tonne of steel. Emission factor from Delucchi (2003b). See Table 10 in the worksheet folio.

Where do emissions come from? Carbon dioxide, the principal greenhouse gas, is released as an essential byproduct of combustion: it's the high-temperature combination of hydrocarbons in the fuel — natural gas is mostly methane (CH₄), which is three-quarters carbon and one-quarter hydrogen by weight — with oxygen in the air that releases carbon dioxide and additional heat. Carbon dioxide comprises 94 percent of the total supply chain's emissions — nearly all of the CO₂ from fuel combustion — with methane the remaining six percent.

Every segment of the supply chain emits greenhouse gases. Liquefaction plants use enormous amounts of energy to generate power and run compressors that chill the natural gas to below its boiling point. Production platforms, pipelines, and the Cabrillo FSRU's re-gasification units are all energy-intensive, which essentially means that large quantities of fuels (mostly natural gas) are converted into CO₂ and emitted to the atmosphere. Production platforms and gas processing facilities routinely flare some of the throughput gas, or flash gas, chiefly for safety reasons, and the CO₂ from flares are estimated. Also, CO₂ is typically produced with natural gas, although the gas from Scarborough is reportedly very low in CO₂ (~1 percent).⁴ Most of this CO₂ must be removed from the natural gas feed at the liquefaction plant and is vented to the atmosphere along with nitrogen, sulfur, helium, and other contaminants.⁵ LNG carriers use marine diesel fuel and/or LNG boil-off gas for propulsion, with substantial CO₂ emissions for the trade route across the Pacific Ocean. Each of these supply chain segments will be described and quantified below.

Carbon dioxide represents 84 percent of total U.S. greenhouse gas (GHG) emissions, methane emissions comprise 9 percent, and nitrous oxide and various halocarbon gases the remaining 7 percent. Methane is important in the supply chain insofar as methane routinely leaks from gas pipelines, storage tanks, compressors, valves, flanges, and seals; methane is also directly vented from the gas processing plant. While routine leaks and vents are not large in terms of mass flow, methane is a greenhouse gas 23 times more powerful than CO₂ per unit mass. Finally, not all of the methane is fully combusted when gas is burned, and these quantities must also be counted.

Overall results

BHP adequately estimated emissions of greenhouse gases arising from the start-up and operation of the proposed Cabrillo Deepwater Port, the energy and emissions from the unloading of ~2.2 LNG carrier berthings per week, emissions from fuel used by the Cabrillo receiving terminal's tugs, tenders, and crew boats, and the main emissions source at Cabrillo: natural gas used in the FSRU's re-gasification units. BHP's estimate totals 261 tonnes of CO₂ per year, including a small amount of methane from incomplete fuel combustion.⁶

⁴ BHP has indicated that Indonesia is an alternate source of natural gas. The gas field has not been identified, nor has the gas been characterized. Thus it cannot be ascertained if the source gas is higher in carbon dioxide content than the gas from Scarborough. CMS has not modeled the supply chain emissions from this secondary source.

⁵ CO₂ can be captured and re-injected into oil or gas field for re-pressurization and enhanced recovery, or otherwise sequestered away from the atmosphere. BHP has not, to our knowledge, investigated such opportunities to reduce project emissions anywhere along the supply chain. Nor do we know if BHP has signed a Greenhouse Challenge Co-operative Agreement with the Commonwealth Government. Western Australia does require an emissions mitigation plan, and greenfield projects such as Pilbara are subject to environmental and emissions guidelines. See Chiu (2002), Office of Environment and Heritage (2003), and BHP Billiton Petroleum (2005).

⁶ BHP omits estimating methane leakage from the FSRU ("since fugitive leaks from the FSRU process equipment will be composed of primarily methane, they are not regulated by permit or source-specific requirements," and are thus excluded, BHP (2005), section 3.6). The BHP permit application also omits emissions from fuel consumed in construction of the mooring facilities and laying the pipeline from the FSRU to onshore natural gas infrastructure. CMS has made a rough estimate of fuel consumed and added the resulting emissions to the Cabrillo start-up and annualized into the supply chain operating emissions with a 25-year time horizon.

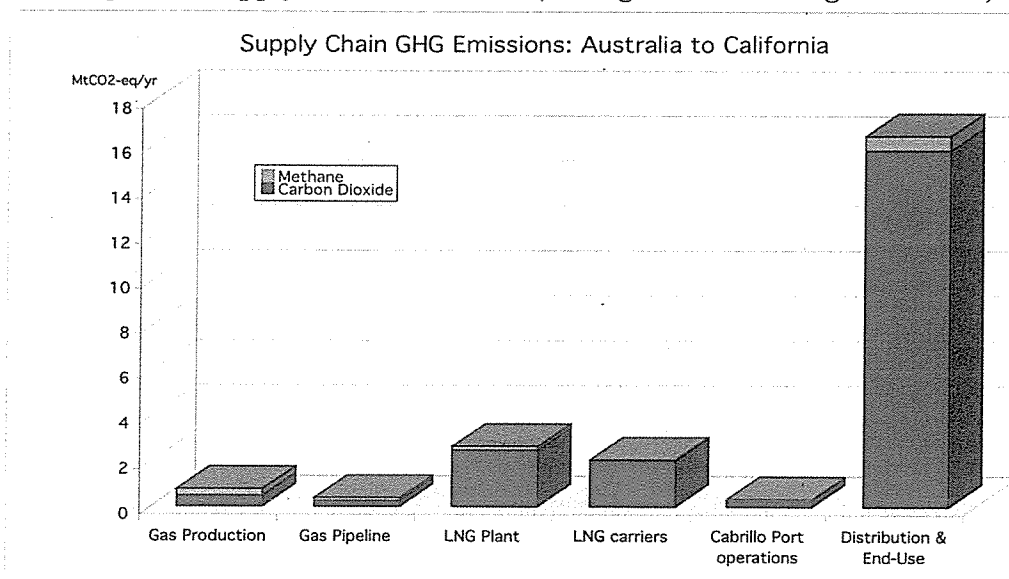
Table 1: Supply Chain emissions (average of low and high estimates)⁷

Supply-chain segment	Methane thousand tonnes of CO ₂ -eq	Carbon Dioxide thousand tonnes of CO ₂ -eq	Total	Percent
Gas production (Scarborough)	297	494	791	3.5
Gas pipeline to Pilbara LNG	135	264	399	1.7
Liquefaction plant at Onslow	175	2,512	2,687	11.8
LNG carrier fleet, Australia ↔ California	47	2,048	2,095	9.2
Cabrillo Deepwater Port Operations	85	261	346	1.5
Cabrillo Start-Up (annualized, 25 yrs)	negl	0.4	0.4	0.0
Ultimate gas distribution & combustion	650	15,852	16,502	72.3
Total supply-chain GHG emissions	1,389	21,434	22,823	100.0
Percent	6.1	93.9	100.0	

Note: BHP Billiton's estimate of annual emissions at Cabrillo totals 261 thousand tonnes CO₂-eq (288 thousand tons CO₂-eq). Note that the table is in metric tonnes (1 tonne = 1.1023 tons).

BHP's estimate of emissions from the Cabrillo Deepwater Port operations represents 1.5 percent of the supply chain emissions as estimated by Climate Mitigation Services (Table 1). Emissions from Cabrillo operations are significant, especially in terms of local air quality if not global warming, but clearly pale in comparison (by a factor of 66 to 1) to emissions from the other elements of the supply chain required for gas delivery to southern California. The major component is, not surprisingly, combustion of the delivered fuel. Compared to the emissions from end-use combustion of the gas — which is a common measure of the global warming contribution of natural gas — the rest of the supply chain emits an additional 44 percent.⁸ Methane is 6.1 percent of the total. The energy-intensive liquefaction plant and the LNG carrier “pipeline” across the Pacific emit ~twelve and nine percent of total emissions, respectively.

Figure 1: Supply Chain Emissions (average of low and high estimates)



⁷ CMS has estimated each supply chain segment in a range. The table averages the high and low estimates.

⁸ This fraction is derived as follows: the supply chain total divided by CO₂ from “Gas distribution & combustion:” 22.82 million tonnes of CO₂-eq ÷ 15.85 MtCO₂ = 1.440, or 44 percent “addition” to end-use combustion alone.

SUPPLY CHAIN SEGMENTS AND EMISSIONS ESTIMATES

Natural gas production at Scarborough offshore gas field

According to BHP's plans as stated in its *Construction Permit Application*, natural gas will be produced from the Scarborough subsea gas field 270-km northwest of the Pilbara Coast of Western Australia. The field is jointly owned by BHP and ExxonMobil, lies at depth of 900 m, was discovered in 1979, is shut-in (that is, there is no production facilities in place), and contains an estimated 8 trillion cubic feet (Tcf) of gas reserves. This reserve estimate is under review.⁹

All of the elements of the proposed supply chain between Scarborough and Cabrillo will use natural gas to fuel pipeline compressors, run generators at liquefaction plants, fuel engines onboard the LNG carriers, re-heat the cryogenic fluid in the Cabrillo re-gasification units, etc. Since BHP proposes to deliver 800 million cubic feet (0.8 Bcf)¹⁰ per day to SoCalGas, our first task is to estimate the total amount of gas production required. This detailed analysis is summarized in Table 2 below. Suffice it to say here that the total annual production is not 292 billion cubic feet (800 million cf/day times 365 days per yr) but 379 Bcf/year in order to cover the delivery rate and the supplementary gas requirements. While it may be the case that BHP's production plans cannot satisfy this 30 percent higher production rate, this is not really material. The objective is to estimate total emissions, and whether it is produced at Scarborough or elsewhere matters less than the total quantity involved.¹¹

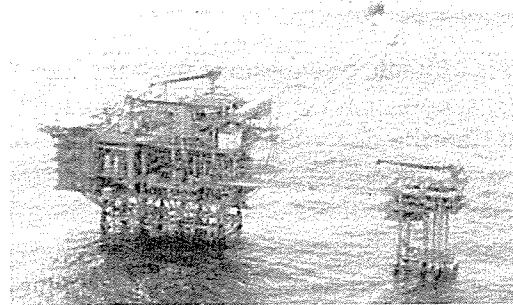


Table 2. Total gas production required for each segment and supply chain total

Segment	Million cf/day	Billion cf/yr	Million tonnes/yr
Production at Scarborough	21	8	0.17
Pipeline to Pilbara	13	5	0.10
LNG plant	103	37	0.81
LNG Carrier fleet	88	32	0.69
Cabrillo Deepwater Port ops	13	5	0.10
Gas deliveries to SoCalGas	800	292	6.28
Total supply chain	1,038	379	8.15

Natural gas in million tonnes or the equivalent in LNG. Also see attached worksheets, Table 1.

⁹ Exxon previously put Scarborough's recoverable gas reserves at 5 trillion cubic feet and "insufficient to sustain a world-scale LNG project." BHP recently completed an extensive reserve evaluation, and BHP and Exxon are now in closer agreement as to the field's reserves. An Exxon spokesperson stated that the company does not necessarily agree that "BHP's LNG plans [are] the best way to develop the reservoir." Wilson (2006); also see Freed (2006).

¹⁰ The U.S. convention is to use mmcf for thousand thousand cubic feet. CMS adopts "M" as million, and "B" as billion, hence MtCO₂ for million tonnes CO₂ and Bcf for billion cubic feet. However, CMS avoids the use of both mmcf and Mcf, preferring to write it out to avoid confusion.

¹¹ That said, other gas sources might contain higher fractions of CO₂ (and vented to the atmosphere). Or it might require supplemental LNG shipments from other liquefaction plants, which would alter the LNG carrier propulsion estimates and perhaps the fleet size. Or BHP could buy LNG on the spot market. This analysis is based on the project as described in the BHP permit application. However, as we will discuss with the LNG plant below, BHP's plans are not adequate to supply the required amount of LNG to propel the requisite delivery rate to California.

The total production quantity determines each subsequent step, since emissions estimates are tied to, say, flaring rates at production platforms, or energy inputs to liquefaction, or the amount of LNG that has to be loaded and transported annually. This parasitic energy consumption drives emissions as well plant capacities and, for that matter, BHP's opportunities to improve plant efficiencies and profitability while also reducing the climate impact of its operations.

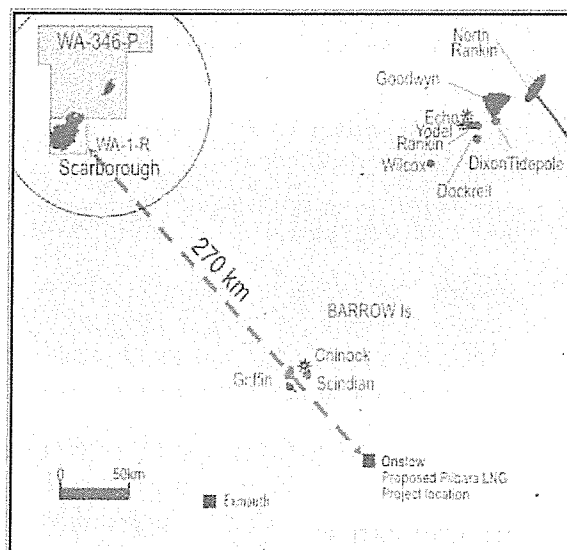
Emissions from gas production include gas flaring, methane leaks, platform energy requirements for compressors, power generation, heating loads, lighting, and hotel loads (for accommodation requirements such as hot water, ventilation, cooking, waste handling, and so forth).

Emissions related to gas production totals 0.79 million tonnes CO₂-eq (MtCO₂-eq), with 0.49 MtCO₂ of the total as combusted and vented carbon dioxide and 0.30 MtCO₂-eq as methane.

CMS' emissions estimates are based on reasonable and transparent protocols. Uncertainties are inevitable, in no small measure because these facilities have neither been designed nor built. CMS did not have access to BHP engineering data other than the scant information published in the permit application. CMS has assumed industry best-practice or, in some cases, improvements over standard practice or industry benchmarks. The assumption made throughout this analysis is that BHP will adopt the best-available technology and low-emission designs within economic and regulatory pressures. CMS makes low and high emissions estimates for each supply chain segment, and uses the average of the two in this summary report.

Natural gas transportation by subsea pipeline

The Scarborough subsea pipeline will transport about 370 Bcf of gas annually to Onslow, Western Australia, where BHP has selected a site to build its proposed Pilbara LNG plant (see the illustration on page 10). CMS estimates that 0.21 to 0.37 million tons of CO₂-eq will be emitted for pipeline energy needs, plus fugitive methane from leaky seals, compressors, and so forth. Methane leakage rates are based on U.S. data for gas production and transmission rates per Bcf of throughput. Since it is a subsea pipeline except for the production compressor station and onshore facilities, CMS reduced the industry gas transmission leakage rate by a factor of ten to five (low and high estimates, respectively).

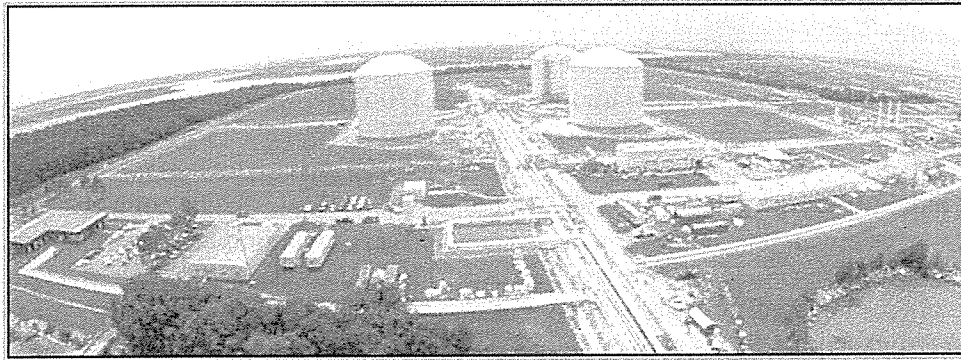


Map of Scarborough natural gas field offshore Western Australia. BHP Billiton *Petroleum Review* 2005.

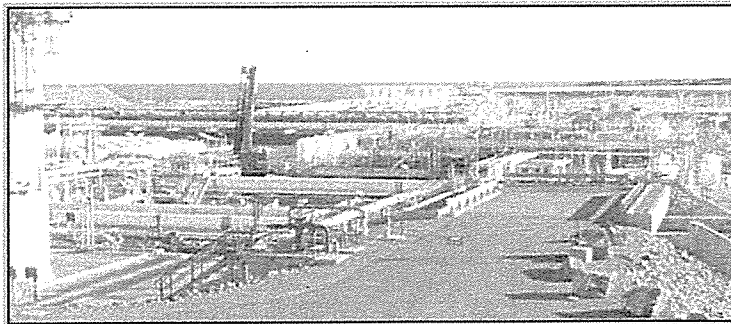
Pipeline compressor energy is the source of about half of the total pipeline emissions. CMS uses a conservative range in the pipeline energy estimate: forty and sixty percent *below* the U.S. industry average for the high and low estimates, respectively, since Scarborough is closer to the LNG plant than typical distances in the U.S. The industry rate is ~2.5 percent of gas throughput consumed for pipeline energy. If CMS had applied the common performance factor, 9.4 billion cubic feet of gas would be consumed for gas transportation, rather than the estimated 4.8 Bcf.

Gas liquefaction: proposed LNG plant at Onslow

Liquefaction is the preferred method for reducing the volume of natural gas in order to “economically” enable its long-distance transportation. Liquefaction also requires purification of the feed gas to remove natural gas liquids, CO₂, sulfur, and other contaminants that could corrode the steel tanks or impede liquefaction or otherwise not meet U.S. natural gas standards. Natural gas liquefies at a temperature of 259 degrees Fahrenheit below zero (-161 °C). Once liquefied, it has to be stored in heavily insulated tanks to minimize the heat transfer that would lead to excessive “boil off” — gasification or volatilization — of the LNG. Liquefaction plants are typically built near shipping terminals, since most LNG is produced for international markets in Asia and Europe and, increasingly, the United States.



Unidentified LNG storage facility, presumably for peaking purposes. Source: US DOE (2005).



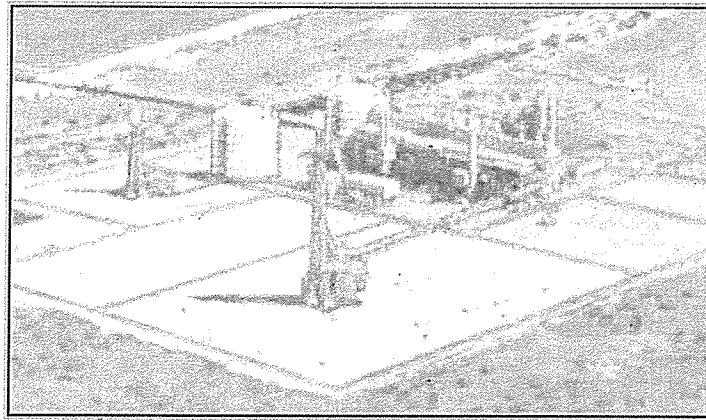
BHP North West Shelf natural gas processing plant. BHP Billiton *Petroleum Review* 2005.

CMS estimated the amount of LNG sufficient to (a) account for LNG boil-off during the 17-day trans-Pacific voyage and any additional propulsion or power generation requirements, including each vessel’s return trip to Pilbara, (b) the amount of natural gas needed to operate the Cabrillo Deepwater Port, and (c) deliver the indicated amount of natural gas to SoCalGas. These

estimates are shown in Table 2 above. If the Pilbara plant is sized to account for these parasitic loads and sufficient to deliver 292 Bcf of gas (equivalent to 6.28 million tonnes of LNG), the required plant size has to be increased from the 6 Mt/yr announced by BHP to 7.1 Mt/yr.¹²

BHP may elect to acquire additional quantities of LNG from other suppliers on the emerging spot market in order to satisfy its indicated delivery rate rather than increase the productive capacity of the Pilbara plant. This uncertainty is relatively immaterial to our principal objective, however, which is to estimate the supply chain emissions of greenhouse gases. Another plant may emit less or more CO₂ and methane, the feed gas may have a higher CO₂ content, but these are unknowns, and we have based our estimates on the most likely chain of events. This includes BHP's plans to construct an LNG plant at Onslow, use natural gas from Scarborough, and ship the LNG in a fleet of carriers to Cabrillo in southern California.¹³

BHP Billiton has not issued any design specifications on the proposed LNG plant. CMS thus does not have plant-specific emissions estimates to draw upon, nor are the selected liquefaction or electric generation or compressor technologies known. BHP has not yet issued a Feasibility report nor prepared an Environmental Impact Assessment. A sketch of the proposed plant based on BHP's site-selection study is reproduced below.



An artist's sketch of the proposed Pilbara LNG plant at Onslow. Source: BHP *Pilbara News*.

In lieu of actual process and technology specifications, CMS used emissions factors for a state-of-the-art facility operated by ConocoPhillips at Darwin, Australia. The Darwin plant uses the Phillips Cascade Process for liquefying natural gas, is a single-train 3.24 Mt/yr plant with one large cryogenic storage tank, and emits an estimated 1.4 million tonnes of carbon dioxide and methane per annum.¹⁴ The CMS methodology for using Darwin's emissions rates involved several steps, each detailed in the attached worksheets:

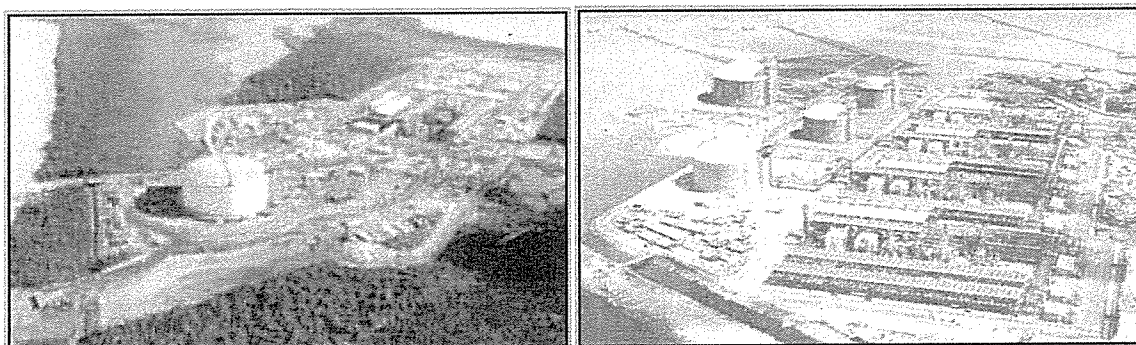
¹² The Pilbara plant will consume ~37 Bcf of gas from Scarborough in the process of liquefying 7.1 Mt/yr of LNG. While many LNG plants use propane and other natural gas liquids contained in the feed gas, BHP has not provided an analysis of the Scarborough, and CMS has converted the LNP plant's energy requirements to equivalent gas.

¹³ Due to the trans-Pacific voyage, BHP will need a fleet of 11 LNG carriers. Assumptions: 138,000 m³ carriers, gas mode on 60,000 HP Wärtsilä 50DF engines (consuming 6,740 m³ one way), 7,900 nautical miles each way, vessel speed of 19.5 knots, and a 24-hour turn-around at each terminal. A current cost of \$160+ million per carrier suggests a "pipeline" investment of \$1.76 billion. Diesel-only fuel mode would increase net deliverable LNG by 13,500 m³ per trip (assuming full re-liquefaction of boil off gas) and reduce the fleet size by one carrier and \$160 million.

¹⁴ The Darwin plant delivers LNG to Tokyo Electric and other Japanese project partners. The first shipment to equity partners Tokyo Electric and Tokyo Gas occurred in Feb06. Emissions are based on estimates (with planned mitigation measures), not measurements, and are drawn from ConocoPhillips (2005) *Operations Env. Mngt Plan*.

1. Scale Darwin's emissions by a factor based on actual LNG requirements for Pilbara, which was in turn increased from BHP's estimated plant size (6.0 Mt/yr) to CMS' estimate that 7.07 Mt/yr of capacity is required in order to deliver 800 million cubic feet of gas to Cabrillo. The resulting scaling factors is thus: Darwin = 3.24 Mt/yr and Pilbara = 7.07 Mt/yr for a ratio of 1:2.18;¹⁵
2. The scaling factor was applied to Darwin's emissions rates per tonne of LNG produced, except for two important adjustments: (a) Darwin's feed gas (from the Baya-Undan gas field 500 km offshore) contains six times more CO₂ than BHP's Scarborough gas, (b) the electricity required to operate acid gas venting process is thus also reduced. Both of these factors are accounted for;
3. The Pilbara "low" emissions estimate is based on Darwin's emissions rates multiplied by the scaling factor between the two plants (and adjusted for the lower carbon content of gas feed, as noted above);
4. The Pilbara "high" estimate is based on a blended emissions factor, averaging Darwin's unusually low emissions rate (0.43 tonnes CO₂-eq per tonne of LNG produced) and the recently completed Train #4 at Atlantic LNG Company of Trinidad and Tobago (0.81 tCO₂-eq/tLNG). This higher emissions factor is again adjusted for Scarborough's lower CO₂ content feed gas.
5. Also, in the Pilbara "high" estimate, the methane venting rate has been increased from Darwin's rate to that of U.S. natural gas industry average in 2004.¹⁶

CMS estimates both "high" and "low" emissions for the scaled-up Pilbara LNG plant for refrigeration compressors (which, due to their very large size and constant operation, require enormous inputs of site-generated power), other plant electricity demands, acid gas venting (removal of carbon dioxide from the feed gas prior to liquefaction), nitrogen rejection units, flaring from numerous sources at the LNG plant, terminal, and loading operations), methane vented directly to the atmosphere, and minor amounts of nitrous oxide emissions. The "low" estimate totals 1.97 million tonnes of CO₂-eq per year, the "high" estimate totals 3.41 MtCO₂-eq/yr, and an average of 2.69 Mt MtCO₂-eq/yr. Methane from venting and incomplete combustion is 5.6 to 7.0 percent of total LNG plant emissions.



The Darwin LNG plant, 3.24 Mt/yr, *left*, & the Atlantic 4-train LNG plant, 15 Mt/yr, *right*.

¹⁵ This assumes that BHP adopts the ConocoPhillips design, liquefaction process, state-of-the-art technology, and mitigation efforts. CMS cannot ascertain that BHP will select these technologies, nor meet or exceed the Darwin plant's emissions reduction initiatives — such as high-efficiency aero-derivative gas-fired turbines to power refrigeration compressors, waste heat recovery, ship vapor recovery, efficient pumps and motors, and cascading emissions benefits from smart design and technology.

¹⁶ ConocoPhillips (2005) *Darwin OEMP*, note to Table 5.2: "A routine venting operation. ... The methane emission rate is 268.8 kg/h with duration of venting assumed to be 7,671 hours per year." CMS has updated the GWP factor from 21 to 23xCO₂, per IPCC's *TAR* report (2001), p. 388. Using the scaling factor applied to compressors (based on the Atlantic Train #4 relative to the Darwin emissions rate) results in a methane emissions estimate of 6,604 tonnes of CH₄. CMS instead applies the methane emissions rate of the US natural gas processing industry (Table 11 in the attached worksheets), namely 28.22 tonnes of CH₄ per Bcf of natural gas consumption, which, in the case of the scaled-up Pilbara plant, totals 366 Bcf per year (see worksheet Table 1).